BROADBAND RADIATION FLUXES FROM NARROWBAND FLUXES

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Introduction

The broadband (BB) radiation fluxes at the top of the atmosphere (TOA) constrain the radiation budget of the Earth-atmosphere system and ultimately determine the energetics of the atmosphere. Most measurements of these flux fields are from non-operational satellites with limited temporal and spatial coverage. However, models of the Earth-atmosphere system, particularly mesoscale or general circulation models, must simulate the radiation budget and dynamics over all times of the day in a given location. Thus, accurate estimates of the BB shortwave (SW; 0.2 - 5 µm) and longwave (LW; 5 - 50 µm) radiation fields are needed at better temporal and spatial resolutions than available with experimental satellite programs such as Scanner for Radiation Budget (ScaRaB) and Clouds and the Earth's Radiant Energy System (CERES). BB SW and LW fluxes have been derived from narrowband (NB) visible (VIS; 0.65 µm) and infrared (IR; 11 µm) radiances for a variety of projects. Generally, these fluxes have been derived during the same time period as the SW and LW observations from other satellites. However, for these NB products to be useful, it is necessary to know their robustness and accuracy at times far removed from their BB anchor points.

This paper examines the accuracy of fluxes derived from VIS and IR data from two different satellites. The conversions from NB-to-BB fluxes are based on coincident Earth Radiation Budget Experiment (ERBE) scanner data taken during 1986. The conversion functions are then applied during later years and validated against independent satellite and aircraft data sets. Geostationary Operational Environmental Satellite (GOES) data taken over the central USA during 1994-1998 are converted to BB fluxes and compared with ScaRab, ERBE Wide Field Of View (WFOV), CERES, and aircraft-measured fluxes during the Atmospheric Radiation Measurement (ARM) program. Geostationary Meteorological Satellite (GMS) data converted to SW and LW fluxes are compared with ERBE WFOV during Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE) over the Tropical Western Pacific (TWP).

Background

The current approach for estimating regional NB-to-BB relationships developed from earlier studies. One of the first uses for BB fluxes derived from geostationary data was to improve time and space averaging methods for CERES (Young et. al. 1998). The GOES BB fluxes were used to fill inbetween ERBE measurements to improve the monthly mean flux. The approach to assess NB-to-BB errors was to compute the NB-to-BB relationship for GOES-6 and Earth Radiation Budget Satellite (ERBS) and then compare the GOES-6 BB fluxes to NOAA-9 ERBE fluxes. Monthly mean NB-to-BB relationships were applied for each of the 5 ERBE scene types over the GOES-6 domain. Some regional (2.5° latitude by longitude) monthly mean LW fluxes were biased by as much as 15 Wm^{-2}. However, a NB-to-BB relationship for each region eliminated the bias. This implies that the NB-to-BB relationship should be applied to limited spatial domains and seasons (especially in the LW).

Another way to remove the bias was to normalize the GOES-6 BB fluxes onto the ERBS measurements. This normalization also reduced the instantaneous RMS error by 40% in the LW and 20% in the SW. Unfortunately, normalization is not possible during most of ARM and TOGA-COARE time periods. In general, datasets taken when coincident BB flux data are unavailable must be converted to BB fluxes using the regional relationship approach. Accurate NB calibrations are critical to the application of these relationships. The accuracy of the resulting fluxes derived from a variety of platforms over long timespans must be determined.

Narrowband Data

The NB VIS instruments do not have onboard calibration, however AVHRR (PM orbit) radiances have been reliably calibrated against stable desert targets for years (Rao and Chen 1996). Therefore all geostationary VIS radiances are first calibrated against AVHRR. To estimate albedo, the NB VIS radiances L are converted to VIS albedo

$$\alpha_n = \pi L / [\delta(d)\ \mu_0 E\ \chi(\mu_0,\mu,\psi)]$$

where δ is the Earth-Sun-distance correction factor for Julian day d, E, the VIS solar constant, μ_0 and μ are the cosines of the viewing and solar zenith angles, ψ is the relative azimuth angle, and χ is the bidirectional reflectance model described by Minnis and Harrison (1984). The bidirectional model is available for three scene types: clear water, clear land and clouds.

The IR temperatures T are calibrated onboard. The nadir NB flux

$$M_{ir} = 1.97\ \pi B(T[\mu_0]) / \gamma(\mu_0)$$

is estimated using the plank function B and a limb darkening function γ defined by Minnis and Harrison (1984) and the 1.97 accounts for the bandwidth.

Baseline NB-to-BB Model

BB fluxes from the ERBE-scanner 2.5° latitude and longitude gridded S9 data product were matched within the local half hour of the NB fluxes. The data were regressed following Minnis et. al. (1995) to yield the following albedo equation,

$$\alpha_b = a_0 + a_1\alpha_n + a_2\alpha_n^2 + a_3 \ln(1/\mu_o) \qquad (1)$$

where α_b is the BB albedo. ERBS viewing zenith angles were limited to 45° and solar zenith angles to 84°. The OLR equation is as follows,

$$M_{lw} = b_0 + b_1 M_{ir} + b_2 M_{ir}^2 + b_3 M_{ir} \ln(RH[\%]) \quad (2)$$

where M_{lw} is the OLR and RH is the column weighted relative humidity above the radiating surface based on the 2.5° global gridded NMC product. The coefficients are given in Table 1 and 2.

ALBEDO	a_0	a_1	a_2	a_3	RMS
ARM	0.057	0.720	0.029	0.052	9.2
COARE	0.027	0.822	0.033	0.048	8.1

Table 1. The NB-to-BB SW coefficients in (1) and the relative error in %. ARM corresponds to October 1986 and COARE to December 1986.

OLR	b_0	b_1	b_2	b_3	RMS
ARM	64.4	6.57	-0.026	-0.32	4.0
COARE	76.7	4.47	-0.012	0.003	3.4

Table 2. The NB-to-BB LW coefficients in (2) and the relative error in %. Time periods are the same as in Table 1 except for ARM which was during April 1994.

ARM Results

The ARM gridded 0.5° (latitude by longitude) fluxes were averaged into the ScaRaB 2.5° grid over the ARM domain of 32°N to 42°N and 105°W to 91°W during April 1994 and July 1994 with the same time and angle constraints as in the baseline model. The SW albedo coefficients were derived from October 1986 GOES-6 and ERBS measurements. The Outgoing LW Radiation (OLR) coefficients were derived from April 1985 and July 1985 measurements. Results are shown in Table 3.

GOES-7	ALBEDO		OLR(Wm^{-2})	
ScaRaB	APR94	JUL94	APR94	JUL94
#	170	15	170	15
MEAN	0.413	0.280	235.8	264.5
BIAS	-0.006	0.004	-1.0	1.3
RMS	0.033	0.028	7.2	7.6
RMS%	8.0	10.0	3.0	2.9

Table 3. Comparison of ScaRaB-scanner with GOES-7 BB fluxes for 2.5° regions during April 1994 (APR94) and July 1994 (JUL94).

GOES gridded fluxes were computed for 8 months (April 1994, October 1994, July 1995, October 1995, April 1996, July 1997, September 1997 and January 1998) over the ARM domain. If a ERBS-WFOV pixel (encompasses entire earth) center falls in the middle of the ARM grid than the 0.5° regional fluxes are weighted by the WFOV cosine response function. The WFOV fluxes are from the Numerical Filter (NF) product which deconvolves the pixel to a resolution of 5° to 10°. The results are in Table 4 and WFOV sampling is sparse resulting in a slightly higher rms.

GOES-	ALBEDO	OLR(Wm^{-2})
#	20	21
MEAN	0.262	250.3
BIAS	-0.012	0.33
RMS	0.033	8.0
RMS%	12.5	3.2

Table 4. Comparison of ERBS-WFOV with GOES BB fluxes for 10° latitude by 15° longitude regions during 8 months between 1994-1998.

Preliminary CERES fluxes from the Tropical Rainfall Measuring Mission (TRMM) satellite were averaged into 1.0° regions over the ARM grid. The GOES-8 VIS was calibrated against the Visible Infrared Scanner (VIRS) also onboard TRMM, which has a precessing orbit and an inclination of 35°. The results are shown in Table 5. The OLR bias may be attributed to the lack of an historical NB-to-BB relationship for January. Also the albedo bias may larger than is indicated because the preliminary CERES albedos appear lower overall to ERBE due to the flatter spectral response of the SW filters on CERES and the particular angular sampling for the TRMM orbit.

GOES-CERES	ALBEDO	OLR(Wm^{-2})
#	1122	1699
MEAN	0.386	221.5
BIAS	-0.012	3.2
RMS	0.033	3.9
RMS%	8.6	1.8

Table 5. Comparison of CERES-scanner with GOES-8 BB for 1° regions during January 1998.

Total Solar Broadband Radiometers (TSBR) were mounted on the Egrett (14km flight altitude), Otter (2km), ER2 (20km) aircraft during the ARM Enhanced Shortwave Experiment (ARESE) during October 1995. The albedo was computed by dividing the upwelling by the downwelling fluxes. These albedos were adjusted to the TOA by the Fu and Liou (1993) radiative transfer model. The profiles were obtained from CERES ARM GEWEX Experiment (CAGEX). Flight leg albedos were computed as the ratio of the up-to-downwelling fluxes summed over the leg. 10 minute legs were used for the Egrett and Otter and 6 minute legs were used for the ER2. Each leg was centered on the GOES-8 image time The mean albedos were compared against the mean aircraft nadir GOES-8 pixel BB fluxes. Table 6 shows the results for clear-sky conditions and Table 7 for cloudy conditions.

GOES-	EGRETT	OTTER	ER2
#	49	39	30
MEAN	0.156	0.185	0.162
BIAS	0.024	-0.007	0.012
RMS	0.028	0.011	0.015
RMS%	18.0	5.8	9.0

Table 6. Comparison of TSBR aircraft with GOES-8 BB SW of flight legs under clear-sky conditions during October 1995.

GOES-TSBR	EGRETT	ER2
#	27	8
MEAN	0.488	0.428
BIAS	0.030	0.014
RMS	0.051	0.019
RMS%	10.5	4.5

Table 7. Same as Table 6 except under cloudy conditions.

From the clear-sky conditions the difference between the GOES-8 BB and aircraft TOA fluxes are same as the aircraft fluxes themselves. Further results and discussion can be found in Doelling et. al. (1998b).

COARE Results

During TOGA/COARE (Nov. 1992 to Feb. 1993) only ERBE-WFOV data can be matched with GMS (10° regions contained by 10°N to 10°S and 140°E to 180°E), but the two datasets cover much different spatial scales. In this comparison no image sharpening was attempted. To understand the scale effects, it was necessary to compare the ERBE scanner and WFOV data. The DEC86 GMS data were matched with scanner data and the scanner matched with WFOV data. The DEC86 GMS albedos have an rms difference of .044 (Table 8) with the WFOV data. This value is close to the square root of the sum (.041) of the squared rms errors of the scanner-GMS fit (.027) and the scanner-WFOV fit (.031). For OLR (Table 9), the DEC86 GMS-WFOV difference of 12.5 Wm^{-2} is approximately equal to $11.8^2 = 7.2^2 + 9.3^2$. While the DEC86 NB to BB fit is unbiased, the scanner-WFOV comparison reveals a bias error and a slope less than one. The WFOV underestimates the high end and overestimates the low end for both the albedo and OLR because extremely clear and cloudy conditions cannot be resolved for the 10° regions. Thus, the DEC86 GMS should be the guideline when comparing COARE with WFOV data. The COARE slope, bias, and rms are very similar to DEC86. This suggests that, if scanner data were available during COARE, the 2.5° GMS BB albedos would have the same

ALBEDO	DEC86 SCANNER	DEC86 GMS	COARE GMS
#	24	16	138
MEAN	0.33	0.39	0.28
SLOPE	0.86	0.82	0.78
BIAS	0.010	.016	0.008
RMS	0.031	.044	.045
RMS%	9.4	11.3	16.3

Table 8. Comparison of ERBS-WFOV with GMS BB and ERBS-scanner albedo for 10° regions during December 1986 (DEC86) and COARE (November 1992 to February 1993).

OLR (Wm^{-2})	DEC86 SCANNER	DEC86 GMS	COARE GMS
#	46	35	404
MEAN	210.1	201.9	223.4
SLOPE	0.87	0.84	0.87
BIAS	3.8	2.9	2.2
RMS	9.3	12.5	11.5
RMS%	4.4	6.2	5.1

Table 9. Same as Table 8 except for OLR.

difference statistics as those shown in Table 1 and 2. Further discussion in Doelling et. al. (1998a).

Conclusions

For both climate regimes, the VIS-to-SW and IR-to-LW conversion appear to provide fluxes almost as accurate as the original ERBE scanner measurements based on a reference dataset of matched fluxes from the ERBE scanners on ERBS and NOAA-9. The instantaneous SW albedos derived from NB fluxes are within ±0.03 (10%) of the reference BB measurements. The NB-derived LW fluxes are within ±7 Wm^{-2} (3%) of the reference data. Both datasets yield a negligible bias. Further reductions may be achieved by normalization with simultaneous BB fluxes if available.

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